

The Delta Adaptive Management Strategy DRAFT (2010-2013)

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Preface (July 2021)

This document does not represent the policies or opinions of NOAA or the National Marine Fisheries Service.

I developed the *delta adaptive management strategy* after the startup of the Estuary and Salmon Restoration Program over a decade ago. The strategy was born a twin to the Salish Sea Restoration Wiki—an ambitious vision for shared synthesis of shared knowledge, independent of institutional limitations. It emerged from the intellectual foment of the Puget Sound Nearshore Ecosystem Restoration Project. This product was drafted solo, but reflects a series of workshops with regional experts. I had three goals: to increase interaction among diverse but seemingly isolated estuary restoration science efforts; to inform the future of nearshore restoration through the ESRP learning program; and to make sense of what I had learned to support delta restoration.

The strategy described here was never fully implemented as ESRP program policy or embraced by our restoration community. I am probably better at having visions than program development. It was an unsolicited collectivist proposal to an unrecognized problem, and I didn't have the horsepower to make it happen. This adaptive management strategy became a buried mile-marker in landform-based adaptive management, followed by metric development for vital signs, work on the estuary implementation strategy, and exploration of barriers to estuary restoration, leading to work on agency coordination.

I dig it out now and offer this framework in its raw form because its architecture still feels relevant a decade later. The need for building collective knowledge through synthesis remains unchanged. The importance of shared models to support collective work remains unchanged. Neither Miradi, Estuary Implementation Strategies, Vital Signs nor Chinook Monitoring and Adaptive Management have successfully scratched this itch for nuanced, dispersed, creative and collaborative work. Regional adaptive management remains underfunded and clogged with vague generalizations and ambiguous conceptual models.

I suspect that right now the best visions of our restoration community are born through close interaction with the living earth, but remain cloistered in the heads of small teams, at the bottoms of institutional hierarchies. We glimpse these visions in 15 minute guest appearances at conferences. The institutional machinery is understandably preoccupied with posturing in front of legislative audiences, but as a result is rhetorically incoherent, heavy on ethos, light on logos. Cloisters like the Puget Sound Ecosystem Monitoring Program Nearshore Workgroup or the Habitat Strategic Initiative Advisory Team are institutionally disempowered, but tending the flame of knowledge.

Our need for large-scale strategic ecological systems thinking extends far beyond river deltas (which served as the birthplace of large-scale restoration in the Salish Sea). We need adaptive management in large-scale floodplain restoration, in the quantification of ecosystem services to mature mitigation markets, in watershed hydrologic restoration, and in the ongoing improvement of our interagency funding and regulatory systems. Global ecological collapse is on us. True

adaptive management is the heart of conservation practice—and yet true adaptive management remains a chimera lost in a maze of institutional silos.

I am convinced that the necessary vision must emerge from local teams in the field. I would advise not waiting for hierarchical validation. The coherence of tangible work in real places is necessary to pull what are inevitably narcissistic institutions towards a deeper collective efficiency and effectiveness. Local restoration teams will need to develop their vision, their networks, their information infrastructure, and their political power. They will need to develop shared purpose and a sense of entitlement to good governance of the commons.

A society capable of ecosystem stewardship will be built on a robust knowledge infrastructure, informed by adaptive management, free information flow, and incremental continuous and collective improvement. This stewardship system will seek collective wisdom over institutional power. This dynamic frontier of restoration is our future. It's not just a practical challenge, but a test of cultural evolution. In this community of practice, I place my remaining hope for my children and their biosphere.

Paul Cereghino

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Purpose

We aim to improve our ability to restore delta ecosystems by integrating project development and restoration design with targeted investigations in delta restoration ecology. These investigations are focused on areas of uncertainty that are most likely to impact the effectiveness and efficiency of public investment in restoration. This wiki format is intended to increase transparency and improve communication within our community of practice. Wiki editors are very welcome to revise and improve topic pages, introduce additional sources of evidence, and refine our assumptions and predictions.

This is a collaborative effort between the WDFW ESRP program and the NOAA Restoration Center. All pages associated with this strategy bear the ESRP Delta Strategy icon, and a click will return you to this page.



To organize our adaptive management efforts we have identified six Critical Dynamics in delta ecosystems. For each of these dynamics we identify topics that we anticipate most strongly affect our ability to achieve restoration goals. Our understanding of these topics changes over time as new evidence is synthesized. The ESRP program prioritizes investigations into those topics where there are opportunities to improve restoration practice and the wiki format allows for that collaborative synthesis to support that prioritization.

Executive Summary

Deltas are important and irreplaceable components of the Puget Sound ecosystem. Delta functions can only be realized where large floodplains enter the sea. Past development practices have reduced historical delta services by 77%, if measured as the area of vegetated tidal wetland. The topography, the character of river discharge, and the biotic communities no longer resemble historical conditions. Sea level and the climate regime that drive river discharge are both changing. In this context, the restoration of delta ecosystem services is uncertain. Responsible investment of public funds in river delta restoration requires that we manage risk around these uncertainties.

The scientific method, when well applied, is a powerful tool for resolving uncertainties in complex systems. A mixture of research, management planning, and adaptive management are necessary to build the scientific evidence that can inform the decisions made by public restoration programs. No single scientific method is likely to provide the needed information, as the kinds of knowledge we need varies. Scientists carefully select the right tool to test and refine a postulate. Therefore it's

important to first identify the uncertainty we wish to mitigate, and then develop the methods necessary to make observations that are precise, accurate, and allow us to make useful comparisons. The Puget Sound restoration community has commonly selected 'monitoring change over time' as the tool of choice for learning, but has found that this method alone may provide very limited predictive power to help us work in complex ecological systems. Concepts like 'adaptive management' are referenced in policy discussions, but are poorly defined, and rarely implemented.



This report proposes a framework for organizing science investment to directly support the restoration of delta ecosystems by:

1. describing a shared understanding of delta ecosystems,
2. synthesizing our current working assumptions about restoration,
3. defining a set of topics where we believe uncertainty strongly affects our ability to reliably restore delta ecosystems, and
4. defining mechanisms within the Estuary and Salmon Restoration Program to investigate these topics.

We propose three programmatic elements:

1. a core monitoring strategy for consistently assessing every project site for problems,
2. an approach for implementing learning projects to support decision making, and
3. an approach for synthesizing evidence that brings refined postulates and theories into decision making.

Our framework builds on a strong body of recent regional work in Puget Sound and the Columbia River Delta that describes the structures, processes, and functions of delta ecosystems. We propose to organize our learning around six critical dynamics: 1) hydrodynamics and channel formation, 2) sediment dynamics and vegetation, 3) biodiversity and food web development, especially 4) salmonid rearing services, and 5) human social dynamics, especially 6) flood and drainage services. These six dynamics were selected through a series of regional conversations among delta practitioners to discuss the issues that motivate and create uncertainty in delta ecosystem restoration. Each of these dynamics integrates scientific disciplines to define a critical 'plot line' affecting our restoration of delta ecosystems.

Within each of these critical dynamics we identify a set of topics and restoration postulates—statements that describe how we believe that deltas function and respond to restoration practices. These topics were selected to describe areas where uncertainty is likely to affect restoration outcomes—they are our greatest sources of risk. By documenting these topics and stating postulates we make explicit our current evidence and our assumptions. By reviewing these postulates, we develop a basis for prioritizing our investments for learning.

We propose that we apply the majority of our regional learning resources toward testing and refining high risk postulates through learning projects, while employing a core monitoring strategy at every new restoration site. Consistent core monitoring allows us to verify that a site is not deviating strongly from restoration goals, allows for detection of some problems, and provides for more robust retrospective analyses. Toward this end our core monitoring strategy, focuses on hydrodynamics, channel formation, sediment dynamics and vegetation. We believe that these dynamics of delta ecosystems provide the best opportunity for rapid assessment, and that biological response, while central to the intent of restoration, is better explored through robust, focused, and carefully designed investigations.

To implement this strategy will require the development of some social infrastructure that is not currently integrated in our restoration systems. Evaluation and scoping of proposed learning projects, and review and synthesis of products, requires some form of scientific peer review. Due to the close social networks within the Puget Sound community, we propose that we draw from a broad regional scientific and policy community base, and include some refereed blind review, so that skilled and knowledgeable reviewers are free to provide robust critique without fear of provoking social conflicts. In addition we are developing a web-based information sharing platform, using a minimally structured open-source user-generated information platform (Mediawiki) to allow for rapid and efficient exchange and synthesis of documents, data and ideas among a diverse community.

These new elements—core monitoring, learning projects using peer review, and information sharing—will be integrated into existing ESRP project management practices. We anticipate that this will not only increase the efficiency of ESRP restoration science investments, but also provide a regional platform for supporting investment in river delta science by a range of stakeholders, with a high level of accountability.

Finally, we propose an initial approach for standardizing the policy level accounting of delta restoration, with a focus on tidal elevation zones, and the restoration of tidal flow. The proposed methods combine [Puget Sound Nearshore Ecosystem Restoration Project](#) data products, with more recent LIDAR based DEM topography being developed by the [US Geological Survey](#). New data will continue to provide new opportunities for evaluating whole delta conditions. However we believe that these existing resources can be efficiently applied to provide an overview of current delta condition and the status of ecosystem restoration, better than an out-of-context list of projects.

Introduction

This report describes a strategy for developing scientific knowledge to support river delta restoration. Despite the completion of approximately 48 publicly supported river delta restoration actions in Puget Sound, the federal and state funding community lacks a cohesive strategy for systematically using that experience to inform future decisions.

The ideas herein were obtained largely from tribal, federal, state, and local partners in restoration, in a collaboration between [WDFW](#) and [NOAA Restoration Center](#) under the [Estuary](#)

[and Salmon Restoration Program](#). Our goal is to reduce risk, and increase the efficiency and effectiveness of restoration. To achieve this goal, we not only need to synthesize existing scientific evidence, but to learn from ongoing projects, and to actually apply this knowledge to decision making in collaboration with on-the-ground partners.

We anticipate this strategy can support how [The Washington Recreation and Conservation Office](#) supports the [Salmon Recovery Funding Board](#) and [NOAAs Pacific Coast Salmon Recovery Fund](#), [Puget Sound Partnership's](#) Puget Sound Acquisition and Restoration Program, the [US Fish and Wildlife Service's](#) National Coastal Wetland Conservation Grants, the [Environmental Protection Agency's](#) National Estuary Program, and other state and federal actors. These funds are already intermingled in delta restoration efforts, but are not applied consistently toward learning. Increasing consistency and communication among funders and implementers across delta ecosystems can reduce redundancy that would otherwise deplete the resources of project implementers, while increasing our rate of learning and information transfer.

Only through collaboration will we achieve the Puget Sound Partnership goal of restoring over 7,000 acres of wetland, recovering the estuarine services critical for salmon and nearshore ecosystem resilience. While the steps necessary to reach this goal are known, it will still require a generation of work. Maintaining clarity and continuity between theory, evidence, and practice can only ease that journey, and benefit the heirs of ecosystem stewardship that will come after us.

Importance of Delta Restoration

The estuarine habitats of Puget Sound provide irreplaceable services to fish and wildlife ([Simenstad et al 1982](#); [Dethier 1990](#); [Greene & Beamer 2005](#)). Seventy percent of the Puget Sound basin flows through 16 large river deltas which historically account for 71% of vegetated tidal wetlands, and 86% of tidal swamp. Estuaries are among the most productive ecosystems on the face of the earth, with among the highest vertebrate biodiversity of all coastal and marine ecosystems ([Johnson & O'Neil 2001](#)). Only 23% of these wetlands remain today. Of tidal swamp, only 7% remains with the rest developed for industry or agriculture ([Simenstad et al 2011](#)). An interdisciplinary panel of scientists from the [Puget Sound Nearshore Ecosystem Restoration Project](#) concluded that river deltas have the highest potential among all nearshore landforms to provide ecosystem services ([Simenstad et al 2011](#)). This high potential requires us to carefully manage these landscapes to optimize these services.

All Puget Sound salmon rear in estuarine environments as they adapt to salt water. Chinook and chum salmon in particular linger during critical phases of growth ([Fresh 2006](#)). Puget Sound Chinook and Hood Canal summer chum salmon populations are nearing a condition where they are at risk of extinction ([NOAA 2005](#)). Recovery planning suggests that estuarine rearing is likely critical to the recovery of some populations ([Beamer et al 2005](#); [SBSRF 2005](#)). Migratory waterfowl, a variety of marine fish, and a broad detrital food web, use estuarine habitats for forage, refuge, and as a source of energy.

The National Oceanic and Atmospheric Association, US Fish and Wildlife Service, Environmental Protection Agency, US Army Corps of Engineers, 15 Tribal Nations, The Puget Sound Partnership, including the Washington State Departments of Fish and Wildlife, Ecology, and Natural Resources, and the Washington Recreation and Conservation Office, along with a range of non-governmental organizations including the The Nature Conservancy and the National Fish and Wildlife Foundation all have programs, priority areas, targets or metrics focused on the restoration of Puget Sound river delta wetlands.

The Challenge of Delta Restoration

Over five generations we have transformed Puget Sound delta landforms into agricultural landscapes or urban ports, bisected by transportation corridors. The Puget Sound agricultural economy, with high value lands in the river deltas and adjacent floodplains, produces over \$1.0 billion in goods every year ([USDA 2007](#)). While this development of deltas appears permanent, delta residents continuously monitor and repair flood defenses and drainage infrastructure. Diked areas of the delta plain have frequently subsided several feet ([Cereghino et al. unpublished data](#)) and are isolated from replenishing river sediment. Sea level is predicted to rise between 6 and 50 inches in Puget Sound over the next 100 years ([Mote et al 2008](#)), along with extreme precipitation events ([Salathe et al 2009](#)).

The rivers that form Puget Sound deltas are both changed and changing. The timing, intensity, and composition of the flood flows that shape the delta landscape have been altered by dams, watershed deforestation, historical logging practices, wetland destruction, and storm drainage infrastructure. Sediment laden flood waters are funneled by levees to deeper waters ([Grossman et al 2011](#)) preventing floodplain accretion. Climate change is likely to further alter the timing of peak flow, the frequency of peak flows, summer low flow, and sediment budgets as less precipitation falls as snow ([Lee & Hamlet 2011](#)), and glaciers recede.

Population levels, distribution patterns, and life histories of the salmonid populations that currently motivate restoration have been altered through broad scale habitat alteration and fragmentation, over harvest, food web modification, genetic modification, new interactions with introduced organisms, and pollution ([NOAA 2005](#)).

The geomorphic processes that created the historical delta landscape follow a predictable pattern. Islands built of sandy river sediment advance the delta front. Islands become vegetated and infill with silt, clay, and large woody debris. Diurnal tidal flows maintain a network of sinuous blind sloughs, while a network of river distributaries pulse, opening and closing to provide the easiest conveyance of river flow to the sea. Patterns of soil anoxia and pore water salinity control which plants establish and thrive, and these patterns vary systematically with floodplain elevation, and the relative influence of the river. The habitat services of deltas are strongly tied to these processes that form and sustain their structure.

The Puget Sound Nearshore Ecosystem Restoration Project published a series of analyses to guide restoration of delta ecosystems in Puget Sound ([Fresh et al 2004](#); [Clancy et al. 2009](#); [Greiner 2010](#); [Simestand et al 2011](#); [Schlenger et al 2011](#); [Cereghino et al 2012](#)). Based on this

body of work, the Estuary and Salmon Restoration Program ([ESRP](#)) funds actions to restore delta ecosystems. These projects attempt to recover the historical resilience and services of deltas by restoring some portion of historical freshwater inputs and tidal flows. No individual action has or will fully restore a whole river delta. Instead, a sequence of efforts incrementally restores some proportion of the historical delta and its processes.

Compared to a delta formed by historical processes, restoration creates a landscape of anomalies surrounded by constraints, and acted on by novel forces. There is no reference or precedent for the evolution that will shape our future deltas. There is no assurance of equilibrium or evolutionary continuity. Under these conditions, restoration is another step in an unalterable ongoing experiment in ecosystem manipulation. The ecological outcomes are not easily predictable, and interact with other ongoing ecosystem experiments, from global climate change, to a doubling of global nitrogen fixation ([Brady & Weil 2008](#)), to regional hydrologic modification. To assume we will re-attain some kind of pre-disturbance system is fundamentally flawed.

This situation, while of our own creation, may foster unnecessary confusion. Delta ecosystems remain ecologically irreplaceable. The places where rivers meet the sea have unique functions that cannot be found or created anywhere else. Our comprehension of the least disturbed delta sites provides our only window into the potential range of functioning in these complex systems. The only path lies in front of us.

Each step of restoration occurs within a web of transportation, industrial, agricultural infrastructure tenuously protected by a system of ditches, dikes and drains. Restoration of deltas is a drama that pits family farms against fish nurseries, as mutually exclusive uses of a finite land base. Underlying the technical challenge of restoration is a vigorous social debate: how much do we value estuarine goods and services, and what costs are we willing to incur over the next generations to sustain human settlements below the high water mark.

Integrating Research and Restoration Practice

We can observe and act in river delta ecosystems, without generating new scientific evidence. We do so every day. However, we *are* supported by an evolving body of principles derived from ecological theories and postulates ([Greiner 2010](#)) and through generations of transferred field experience. By not procuring new scientific evidence, and testing our principles and postulates, as we restore river deltas, we increase the risk that our actions are less than effective. If we wander forward in the absence of scientific evidence, we depend entirely on socio-political processes, to set our goals and chart progress.

However to use science, we face two parallel challenges: 1) to make meaningful observation of complex ecological systems, and 2) to integrate that understanding into policies and behaviors. Neither is assured. We struggle with the scales and interconnections in ecosystems ([Ehrenfeld & Toth 1997](#); [Simenstad et al 2006](#)), making inference in ecosystems ([Holling & Allen 2002](#)), or even understanding the bounds and behaviors of any complex system, including our human systems ([Meadows 2008](#)). We struggle with recognizing and responding to cultural dynamics in

human land use ([Hardin 1968](#)), the potential disconnections between political and ecological systems ([Holling and Meffe 1996](#)), lack of consensus around our cultural construction of value ([Lansing et al 1998](#)), and we face barriers to implementing big ecosystem projects in complex organizations ([Slocombe 1998](#); [Marmorek et al 2006](#); [Boevers 2008](#)). We even struggle with the simpler challenge of implementing useful monitoring in the fast paced restoration arena ([Field et al 2007](#)), seldom asking whether the scientific method is the right tool for all situations ([Cabin 2011](#)).

Monitoring change over time is an ecological research approach that has become popular in the restoration community. This may have emerged out of the needs of wetland mitigation, which largely drove the development of best restoration practice before the listing of salmon under the Endangered Species Act. Mitigation programs use monitoring change over time to determine if a site is 'functioning' or 'not functioning'. Establishing the verifiable condition of a restoration 'site' is motivated by the competitive relationship between the regulator and the regulated. These 'proof of restoration' studies, built from the stated goals and objectives of restoration, have provided the foundation of monitoring education for environmental professionals over the last two decades.

In the design of a "monitoring change over time" research project, practitioners frequently find that they don't have the resources to estimate a range of site scale parameters using random representative sampling. Detecting all change is too broad a goal, and so a devil's bargain is made between being comprehensive and being robust. Professional scientists, with varying levels of field research experience in estuarine ecology, do the best they can with not enough, and so typical restoration monitoring is neither comprehensive nor robust.

Where robust monitoring is developed, another problem may emerge. The objectives of ecosystem and population restoration and management are different and more complex than the objectives of mitigation. Mitigation requires the production of a facsimile of the destroyed site. Ecosystem restoration necessarily considers processes and dynamics at scales larger than a real estate parcel ([Goetz et al 2004](#); [Fresh et al 2004](#)), and ecosystem restoration may require diverse and complementary actions to incrementally achieve a change in both ecosystem state, and processes, to achieve resilience over time.

When faced with the challenge of ecosystem restoration and management, observation of site change over time may not provide the information necessary to inform decision making. While monitoring, if fully implemented, may allow for measurement of a site, hopefully to a control or reference, it may be that the selected parameters don't encompass all the important dynamics of the ecosystem, or whether the target state is, or will be, stable let alone resilient. Monitoring may not determine what is causing change, or creating risk, or what other factors are affecting site evolution, and if those factors are changing, or if the target state will ever be attained or sustained. In many cases, the critical questions of restoration are social and political.

Monitoring change over time may be a very inefficient way to answer the questions of ecosystem restoration. Even if monitoring does provide evidence, knowledge needs to be reviewed, synthesized and repeatedly and consistently delivered to diverse audiences. It is easy to develop a long list of realistic scenarios wherein efforts to build scientific evidence fail to inform decision making:

- Postulates are not developed prior to data collection--experimental design is not based on a full analysis of the situation

- The language leading to the design of investigations is imprecise and poorly defined, leading to misunderstanding between scientists, practitioners and stakeholders
- The needs of decision makers are not considered before gathering new evidence
- Sampling strategies fail to isolate and develop parameters that address the questions being asked
- Ecosystem dynamics include important nonlinear responses or feedbacks that are not detected by simplistic efforts
- Evidence of change is not attributable to the restoration treatment due to insufficient controls
- Poorly targeted quantitative evidence only illustrates the obvious rather than expanding knowledge
- Analyses only applies to a single location, and does not transfer to new situations without a repetition of effort
- Study results are viewed in isolation, and not synthesized and interpreted as part of a larger body of evidence
- Decision makers don't understand the potential limitations or the aggregate meaning of available evidence
- Evidence becomes buried or lost due to personnel changes or poor documentation practices
- The desire to be professionally successful results in promotion of poorly developed evidence
- Useful observations from non-quantitative sources are ignored because they have no quantitative basis
- Decision makers deliberately or unconsciously thwart the open review of scientific evidence
- Social, political, or economic shortcomings in leadership fail to align successive waves of investigation to develop a cogent line of analysis.

Many of these issues arise when we fail to perceive that by “monitoring” we are actually conducting quantitative ecological research for use in political systems. We often call these efforts by a name other than research-- effectiveness monitoring, adaptive management, or evaluation protocols--perhaps to avoid the impression that research does not have practical value. When we attempt to quantify the processes, structures and functions of ecosystems, to inform a decision, we are doing research. To do this well, we depend on the scientific method--a body of theories and practices, developed over generations. Quantitative observation of ecosystems to make inference is ecological research. Without the use of the scientific method, quantitative monitoring is likely to be either useless or misleading.

Because of, 1) the many potential scenarios for failure, 2) the proliferation of scientifically ambiguous research hidden by nomenclature, and 3) the ultimate goal of directly affecting socio-political policy, the design of restoration research must be even more precise, logical, and rigorous than other ecological research. An isolated practice, like monitoring change over time, has no intrinsic value to our overarching purpose of using scientific evidence to improve delta restoration decisions. Data collection only delivers value when methods are statistically

rigorous, executed with a high level of professionalism, and where research methods are designed to effectively inform policy.

The development of a weight of evidence over time does not depend on the deployment of a particular protocol. By contrast, over-reliance on a single approach to sampling or measurement may in fact reduce the effectiveness of ecological research ([Holling & Allen 2000](#)). Quantitative evidence gathered in different settings using different methods may increase the certainty of inference through weight of evidence, as long as each investigation is designed as robust ecological research.

This does not suggest that restoration capital should be spent on all manner of basic ecological research. The delta restoration community is faced with specific and known concerns and challenges. In the case of large river deltas in Puget Sound, we have a broad agreement about the importance of ecosystem stewardship ([PSP 2012](#)), and have documented wide scale degradation ([Simenstad et al 2011](#); [Fresh et al 2011](#)). Restoration hinges on the assumption that our efforts lead to the development of ecosystem services. To make capital investments in restoration, without investigating known risks and tradeoffs is a poor management of public assets. Restoration practice must reclaim targeted and applied research as an integrated and critical tool of restoration practice. This work requires collaboration between scientists and policymakers built on shared understanding and development of a cohesive body of evidence. It will take a level of clarity, documentation, and collaboration rarely found in governance.

This work is possible. We are increasing our understanding of tide gate effects on salmonid rearing ([Lyons & Ramsey 2013](#)), are building our understanding of vegetation distribution ([Hood and Hinton 2003](#); [Hood 2006](#); [Beamer 2012](#)), and tidal channel formation ([Hood 2002](#); [Hood 2004](#); [Hood 2007](#)). These new sources of evidence expand and refine policy debate and improve restoration practice. This delta adaptive management strategy leverages these impromptu practices, within a shared framework, and the strategic application of capital assets in the context of project development.

A Proposal for Restoration Learning

While we may lament the lack of resources for restoration science, to increase those resources we must demonstrate the value of restoration science. Restoration science provides value when it informs a decision that changes our practices and decisions. To achieve this continuity requires a shift in funding methods and priorities from generalized monitoring of change over time at project sites, to development of carefully designed ecological research designed to achieve learning goals that are anticipated to affect restoration policy and design.

Capital project selection and implementation is the moment where, ideally, best professional judgment draws on scientific evidence to allocate public resources. The funding decision is where scientific evidence is made clear, or is muddled over. It is where risks are identified, and where best practices are rewarded. Limitations in our ability to integrate science-based planning and the science of restoration into our funding decisions increases our risk of failure. The solution comes through better integrating scientific processes and funding decisions. Funding programs are positioned and authorized to act in such an integrative manner.

How do we select a restoration research action? This framework proposes that we maximize the leverage our on-the-ground action to test and refine postulates that 1) strongly affect restoration outcomes, 2) are weak in empirical evidence, and 3) where we anticipate new knowledge will lead to a change in policy. This does not limit research to the boundaries of restoration sites, which would reduce our ability to leverage natural experiments, the work of other actors, or observe important off site effects. It does require careful design, and rigorous vetting of new research actions.

Even if we achieve this focus, we will still face difficult decisions. Typically, the amount and type of capital restoration funds available precludes investments in long term intensive studies to answer critical questions about large scale biotic response to system restoration. Capital restoration program funds are more suited to facilitating smaller incremental improvements to restoration methods. As a result, we must live with assumptions about long-term, large-scale outcomes that are incorrect or insufficient for making good decisions and ensuring the success of our restoration projects. This product aims to create common ground between political leadership, project developers, funders, and researchers working in delta ecosystems so that we can coordinate our efforts to build a body of knowledge that is applicable to policy and design.

This document is not intended to replace planning by the [Puget Sound Nearshore Ecosystem Restoration Project](#) or the further refinement of the Shared Strategy for recovery of Pacific salmon. Any work we accomplish here may strengthen these related efforts. By focusing on a single physiographic system ([river deltas](#)) we are better positioned to leverage and synthesize learning and disseminate knowledge.

We propose to accomplish the following four tasks here:

- Provide a generalized ecosystem model to organize our shared understanding delta ecosystem.
- Define our assumptions (however superficially) about how restoration efforts interact with delta ecosystem dynamics by integrating information from restoration project practitioners as well as ecological researchers.
- Define a set of topics that reflect opportunities to improve restoration practice and reduce risk, and state our working assumptions.
- Propose programmatic methods for investing in targeted research and integrating new knowledge into decision making.

These tasks will prepare us to maximize learning that can improve restoration practice. Six elements of the [Estuary and Salmon Restoration Program](#) will require development to support implementation of this strategy:

- **Evidence synthesis and transfer** - Contractual and network-based mechanisms for capturing and integrating new evidence and transferring information between practitioners.
- **Revision of RFPs and selection criteria** - Modification of the methods used to select and contract projects.
- **Design Predictions** - Incorporating specific predictions about [critical dynamics](#) into project design.
- **Core monitoring** - Defining a set of observations that are consistently applied to all river delta projects, used to establish baseline conditions and detect problems.

- **Learning projects** - competitively selected investigations, ranging from short term intensive efforts to longer term low intensity efforts, designed to affect policy by testing and refining postulates on priority topics.
- **Research gaps** - Specific pivotal issues that are beyond the reach of project-based learning, where we actively advocate for the funding of basic ecological research.

Delta Components and Processes

To make decisions while working in delta ecosystems we make assumptions about how delta ecosystems work. Ideally, these assumptions are based on repeated and comprehensive measurements of the physical, chemical, and biological dynamics of the systems in which we are working, along with a range of comparable systems in different states. These models would be at our fingertips, with which we would predict the outcome of alternative treatments.

Unfortunately we have no complete empirical model of delta function. Instead we primarily work with a few isolated models, connected by conceptual diagrams, built from limited data points when available, and held together with best professional judgment. Our understanding is often extrapolated from similar systems or even other ecological disciplines. We mix data and professional intuition to make good predictions. This is fitting--most large-scale and significant human ventures are conducted in this way. Science is a useful way-finding tool, but rarely provides us a complete map.

To manage risk, it is useful to acknowledge, document, and revisit our current working assumptions, including the data and experiences upon which they are founded. By ruthlessly considering the imprecision and inaccuracy of our current map, we remain cautious as we commit resources to explore uncharted territory. We are more likely to anticipate problems, and avoid pitfalls. This effort, and the use of this interactive on-line tool, are intended to support that process.

There are diverse approaches for describing an ecosystem for planning. The Open Standards for Conservation (Open Standards) describes ecosystem 'targets', and defines a logical chain of human impacts on those targets ([CMP](#)). The European Environmental Agency, with its Driver-Pressure-State-Impact-Response (DPSIR) framework, is similar to The Open Standards, in that the ecosystem itself is described as being in 'a state', around which human forces, pressures, impacts and responses revolve ([EEA](#)). The [Salmon] Recovery Implementation Technical Team ([RITI](#)) draft adaptive management model elaborates on the Open Standards approach by including 'drivers', recognizing that ecosystems are shaped by intrinsic dynamics other than human impacts.

[PSNERPs](#) Nearshore Conceptual Model ([Simenstad et al 2004](#)) provides a more elaborate description of 'ecosystem state', wherein the functions of nearshore ecosystems emerge from interaction between structures and processes. Structures are the current arrangements of the physical and biological components. Processes are the physical and biological forces that cause structure to change over time (specifically, fluxes, energy transfers and transformations). The description of ecosystems both in terms of their structure or state, but also in terms of their

processes or drivers, has been embraced by a range of regional authors (Clancey 2009; Hood 2006; Fuller in draft, and Simenstad 2011a; Roni et al. 2002; and Beechie 2003). We distinguish between processes and structures to organize our delta ecosystem conceptual model. The strong influence of physiographic processes in the nearshore lead toward a consideration of ecosystem processes in restoration planning ([Goetz et al 2004](#)), a call that has been repeated in other dynamic systems (as with [Beechie et al 2010](#) for river restoration).

Delta Processes, Drivers, and Regimes

River deltas are deformable, and are continuously fluctuating and evolving, so developing an explicit understanding of processes is central to any assessment of delta ecosystems. Our impacts on the delta environment are amplified (or muted) to the extent that our labored manipulations of structure in turn affect ecosystem processes. For example, we may remove a dike over a small footprint, but the vast impact is realized through the restoration of tidal flows. In deltas, the effectiveness of our restoration efforts depend on our restoration of processes ([Goetz et al 2004](#); [Simenstad et al 2006](#); [Shipman 2008](#); [Bartz et al 2013](#)).

[Shipman \(2008\)](#) and [Simenstad et al \(2011\)](#) each provide a slightly different list of physical processes responsible for forming delta structure. These process lists represent an attempt to organize our thinking in the face of a complex system full of feedback and non-linear relationships. While these lists of processes are based on observable phenomena, each process does not function in isolation. There are linkages and interactions among processes, such that if we envision or observe each process in isolation, we are likely to fail to predict the behavior of delta ecosystems.

Table 1 - Delta Processes identified by Shipman 2008 and Simenstad et al. 2011.

Shipman (2008) defines 11 processes	Simenstad et al. (2011) identifies 8 processes	Discussion
Freshwater input	Freshwater input	River discharge is clearly a primary system driver. The strong relationship between freshwater input and sediment input is somewhat disconnected.
	Fluvial sediment supply	Simenstad et al. distinguishes between sediment input to the system and the freshwater input, although the two are closely linked.
Tidal exchange/hydrology	Tidal flow	The twice daily pulse of marine water is clearly a system driver.
Channel formation	Tidal channel formation	It is likely useful to describe differently the development and maintenance of tidal channels as different from the migration and avulsion or 'switching' of alluvial channels. Both differentiate between the drivers of channel structure.
Channel migration/avulsion	Distributary channel migration	
- Marsh accretion - Overbank deposition (river dominated) - Natural levee formation (river dominated) - Barrier formation (wave dominated) - Longshore sediment transport (wave dominated) - Fluvial sedimentation—delta growth	- Sediment transport - Sediment erosion and accretion	Shipman distinguishes between bed load and suspended load deposition processes, and further distinguishes between how fluvial and longshore processes shape delta structure. The Simenstad et al. differentiates between the movement of sediment and whether that movement results in an increase or decrease from a surface. While shipman identifies marsh accretion, the relative influence of primary production in affecting accretion is not described.
Subsidence (long-term)		Shipman identifies the critical but subtle process of subsidence, but does not explicitly include isostatic rebound.
	Detritus import and export	Simenstad et al. describes the movement of organic materials separately from that of sediments.

These process lists consistently identify three strong drivers: tidal flow, freshwater inputs, and wind-driven waves. Tides penetrate the delta front en masse with a dissipation of force as tidal flow moves uphill against the resistance of freshwater inputs and increasingly confined topography. Freshwater flows pulse with weather events, and are distributed downhill through a system of alluvial distributaries. Wind waves primarily work the delta face, perhaps shaping tidal flow through the formation of bars and shoals. These driving processes result in a pattern of local process regime, which varies systematically over the length of the delta landscape from tidal flats and through the delta to river floodplain.

If we reconsider Table 1 in light of these three drivers, we can simplify understanding of delta dynamics by grouping some of these processes into networks. We propose two major physical dynamics within river delta that fundamentally describe delta structure. First are [delta hydrodynamics and channels](#) by which freshwater inputs, either muted or reinforced by tidal flows maintain a system of channels that convey and mix moving water. Within the flux of delta hydrodynamics, [sediment and flotsam](#) are deposited, building the delta plain in a feedback loop with vegetation, with vegetation both increasing accretion ([Leonard & Luther 1996](#)), and shifting composition and structure in response to increasing elevation and salinity. Wood entrained in the sediment-vegetation system may have similar roles as in floodplain systems (see [Roni et al 2002](#)). The local behaviors of these two dynamics largely drive the structure and evolution any particular location in the delta—a local process regime.

The behavior of this two part system is played out through local geochemical and ecological processes, each dependent on the local process regime. Local process regime can be observed in most of the biotic structures we see every day (Table 2; Simenstad et al. 2011).

Table 2 - Simenstad et al. (2011) offers five classes of geochemical and ecological processes anticipated to be important in the nearshore.

- **Hydrogeological processes:** burial, sediment sorting and stratification, infiltration and exfiltration, and seepage.
- **Geochemical processes:** transformation between dissolved and particulate organic matter, either by flocculation or uptake, transformation of nutrients between organic and inorganic forms, and change in inorganic nutrient states.
- **Primary production:** both autotrophic (photosynthesis-based) and heterotrophic (detritus-based)
- **Food web interactions:** primary production, secondary/tertiary production, secondary/tertiary consumption
- **Physiological/Metabolic Processes:** excretion, respiration, salinity/temperature resistance, reduction in predation risk (refuge), individual growth, reproduction, recruitment, competition, symbiosis, and behavior like migration, social interaction, or reaction to abiotic factors.

Ironically, while human endeavors and concerns drive our interest in ecosystem processes (even prompting the writing of this report), the work of human populations in deltas are typically not included as an 'ecosystem process'. The Puget Sound Partnership has attempted to capture human effects in management models, dramatically increasing their complexity, while achieving a very limited command of the full range of human drivers and feedbacks. We include human social dynamics as a component of our delta ecosystem model because of the importance of our communities as a component of delta ecosystems, and perhaps the most poorly analyzed ecosystem driver. In particular, the management of surface water to limit flooding and improve drainage is critical. The local and informal understanding of motives, concerns, and landscape dynamics within human communities must become exposed and resolved for us to solve the delta management challenge.

Delta Structures

Structures are easier to measure than processes because matter is easier to measure than energy. Current landscape structure provides a cumulative snapshot of past processes. By comparing structure over time, we can describe the work of processes, and attempt to predict future conditions. Structures are used to organize sampling design, and in turn, for better or for worse, structures are then used to infer habitat functions. Restoration practice commonly attempts to restore historical structures, sometimes assuming that historical ecosystem functions will follow.

Our ability to perceive ecosystem dynamics is limited by what we can see and measure. Ultimately, an investigator decides what structural measures are most appropriate, given the resources and technologies available, and designs an investigation in the context of current theory.

The last decade has brought a surge of interest in the spatial description of delta structure. Shipman (2008) differentiates among six components of delta systems. [Simenstad et al. \(2011\)](#) repeat these components only adding a distinction between 'tidal floodplain' and 'alluvial floodplain'. In a contrasting approach McBride et al (2009) classifies seven kinds of linear shoreline segments occurring within deltas (Table 3), and in appendices suggests a relationship between these segments and Shipman's 'landform' classification, different than components.

The crosswalk proposed by McBride et al. may add some confusion to a description of delta structure by neglecting the different intent between Shipman's conceptual classification of whole delta 'landforms', and McBride et al's practical classification of shoreline segments. For example, you are more likely to have a McBride shoreline called 'delta lagoon' within a shipman 'wave-dominated delta', however this increased potential for a delta lagoon to be present in a whole system dominated by waves, does not indicate that the two classes are equivalent. The McBride et al. framework does add some additional components to Shipman's list of components, more fully encompassing structures like lagoons, formed through the interaction of deltas and littoral cells, and the presence of drowned stream channels within many delta systems.

Table 3 - Components of delta ecosystems

McBride et al (2009)	Shipman (2008)
Segments:	Components (Modified by
• tidal delta • delta • delta lagoon • tidal channel marsh • tidal channel lagoon • drowned channel • drowned channel lagoon	Simenstad et al 2011): • alluvial floodplain • tidal floodplain • salt marsh • tide flats • subtidal flats • distributary channels • tidal channels

While Simenstad et al. follows Shipman in the identification of delta landforms, they do not use a geomorphic analysis within the delta unit, but rather use mapped vegetation to identify zones based on salinity regime. This approach is consistent with the vegetation-based wetland classification proposed by Cowardin which informs Collins and Sheik (2005). Collins and Sheik provide the historical reconstructions of delta landscapes critical for the change analysis completed by [PSNERP](#). In practice however, the use of general vegetation zones to define delta composition blurs the distinction between channel and floodplain components proposed through Shipman's components. Braided river distributaries, large tidal channels, tidal flats and lagoons become equivalent due to their lack of vegetation. [Griffith \(2005\)](#) provides an example of a purely structural assessment of the [Stillaguamish](#) flats--appropriate for its own purposes--considering sediment texture and vegetation, regardless of the presence of fluvial processes.

A structural analysis of deltas for the purpose of restoration would be at a disadvantage if it did not consider the relationship between channel networks and the delta plain. Somewhat parallel

to Puget Sound change analysis work, a [UW-USGS](#) team developed a nested six scale estuarine ecosystem classification strategy for the Columbia River Estuary ([Simenstad et al 2011b](#)). This approach attempts to provide a more comprehensive multi-scale method for describing the current conditions of large estuarine landscapes. Four of those levels may have potential application to the description of Puget Sound deltas in order of decreasing scale:

- Hydrogeomorphic Reach divides the landscape longitudinally, defined by a variety of hydrogeomorphic thresholds including: extent of salt intrusion, extent of estuarine turbidity, mean extent of current reversal, from the extent of tidal water level fluctuation to the mouth, and all areas between, which have the historical or current potential to be estuary. These zones are not adequately defined in Puget Sound deltas by existing data, but offer a conceptual alternative to using historical vegetation patterns to divide major zones within a delta. [Jay & Simenstad \(1996\)](#) describes the effect of shifting hydrogeomorphic boundaries on sediment dynamics in the [Skokomish Delta](#).
- Ecosystem Complex defines major units within a Hydrogeomorphic Reach. An initial partition is made between channel features and floodplain features. Delineation of channel features uses vegetation and bathymetry, while delineation of floodplain features relies more heavily on interpretation, of geologic and soil mapping, wetland mapping, and vegetation observable in aerial photography.
- Geomorphic Catena – this level involves extensive interpretation of remote sensing data to define discrete biological units within ecosystem complexes.
- Primary Cover Class – A final quantification of structure is provided by a land cover classification using aerial photo and LANDSAT interpretation.

The Columbia River Delta is exceptionally large. Four levels of sub-division may be excessive within Puget Sound deltas. However defining hydrogeomorphic reaches based on salinity and hydraulic phenomena may provide a more robust zonation than the use of historical vegetation maps that reflect hydrodynamic environments that no longer exist. The definition of ecosystem complexes based largely on the presence of tidal barriers has been developed in the Snohomish ([Stanley et al 1997](#)).

However, current conditions differ from the regular structural patterns of historical deltas. Channelized rivers create new proto-deltas, hydrodynamics have been altered, and diked wetlands have subsided at different rates. Current deltas contain a very irregular maze of fluvial 'chutes and pools' not found in unaltered deltas. Restoration may ultimately alter 'hydrogeomorphic reach' by altering tidal prism and site hydrodynamics.

It is unclear how a particular approach of structural measurement actually adds value to management decision making within an individual delta. In ecosystem management, accounting systems can easily precede a clear understanding of their scientific value. Accountability systems have sociopolitical value independent of their scientific rigor. These concepts are explored further in the [Delta metrics project](#), where the [ESRP](#) program is working to develop an restoration accounting approach that integrates current aerial photography and digital elevation

models with [PSNERP](#) change analysis data to quantify delta structure before and after restoration, and can integrate our evolving understanding of what makes a delta 'restored'.

Delta Ecosystem Functions, Goods and Services

Twice a day, the delta becomes a vegetated lake intersected by deeper channels with complex patterns of salinity and turbidity. Twice a day the delta is a wet meadow and shrubland complex intersected by muddy trenches and streams. Over a day, over a season, over a year, this complex system provides a range of different services to people and wildlife. Through diking and drainage of delta landscapes, we obtain a different set of ecosystem services. It is because of how we value these various services that we are concerned about the structure and processes of deltas (Leschine and Peterson, 2007).

The Millenium Ecosystem Assessment framework has been broadly embraced as a tool for describing this range of goods and services (MEA 2005), considering not only the goods we extract for provisioning, but also the cultural services we derive, and the supporting and regulating feedbacks critical to ecosystem functions and resilience. Simenstad et al (2011) combined the MEA framework with a best professional ranking of relative service provision, to suggest that delta ecosystems provide a greater diversity of ecosystem services than any other nearshore landform in Puget Sound. Batker et al. (2010) proposes some generalized quantification of ecosystem services, many of which originate in delta wetlands.

A meeting of delta restoration practitioners in 2008 was asked what aspects of delta restoration were most compelling to the communities within which they work (see [our development notes](#)). They indicated that flood and drainage services were valued by members of surrounding communities, while juvenile salmonid rearing was responsible for the financing of much of their work, with salmon not only representing an economic commodity, but also a cross-cultural heritage and way of life. Further that we risk not only loosing services, but loosing the opportunity to recover service resilience at a landscape scale.

Ultimately we are concerned with how deltas provide goods and services. Accurately measuring the provision of goods and services is more difficult and therefore more expensive than either measurement of structure or process (see [delta topics associated with this strategy](#)). However, defining factors that drive service provision and resilience may be among the most important components for defining restoration policy.

Differences among Puget Sound Deltas

Not all Puget Sound deltas are alike in the relative dominance of drivers, local process regime, their resulting structure, or their provision of ecosystem services. Post glacial geomorphology, river basin character, and development patterns all conspire to create variation in deltas. [Shipman \(2008\)](#) suggests distinguishing between whole delta systems based on the relative influence of river flow, wave energy, and tidal processes in affecting hydrodynamics. The geologic setting of each delta may affect the degree to which each of these forcing processes drives the evolution of delta form.

[Simenstad et al. \(2011\)](#) did not choose to differentiate between delta system types as suggested by Shipman. [Sixteen sites](#) were delineated where major river floodplains enter marine waters. The differences between these systems and slightly smaller systems like the [Union Estuary](#) or the [Snow-Salmon Watershed Ecosystem](#) are a matter of professional judgment.

Collins and Sheik (2005) delineated and categorized coastal wetland complexes based on a geomorphic approach, and so integrate well with Shipman. Steep fan-type deltas, deltas that fill glacial troughs, and the extraordinary Skagit-Stillaguamish Complex are placed in distinct groups. Collins and Sheik both precede and likely inform the conclusions of Simenstad et al. (2011) in that they differentiate between 'large deltas' and other estuaries located in coastal embayments.

Cereghino et al (2012) uses a cluster analysis to differentiate between the 16 delta process units identified by Simenstad et al. based on watershed size, historical wetland size and character, and delta shoreline length--grouping all Olympic Deltas, differentiating Olympic from Cascade Deltas, and separating the Skagit and Snohomish deltas as uniquely large systems, accounting for approximately half of all delta wetlands in Puget Sound. The magnitude of current river discharge may be altered by human diversion (in the case of the [Duwamish Delta](#)) or by geologic history (as with the [Samish Delta](#)), making the current river more or less fitted to the current delta plain. The character of river discharge may vary among systems as well, based on the origin of river flow in glaciers, and how rivers entrain and deposit sediments ([Czuba et al 2011](#)). Cereghino et al. (2012) further identifies a set of 7 coastal inlets where relatively large watersheds enter large tidal wetland systems.

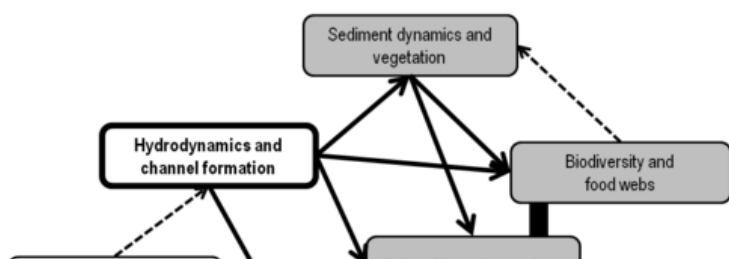
The impact of human development also varies dramatically among systems. Different deltas vary dramatically in how the damming of rivers affects delta evolution, and how future population growth within Puget Sound is anticipated to impact individual delta sites ([Cereghino et al 2012](#)).

Due to the limited number of delta sites, all these different sources of information are generally complementary in that they, in combination, provide a more complete understanding of each delta ecosystem, and are easily integrated into a cohesive and unique story for each delta site. These differences among deltas have not been articulated as affecting delta restoration strategy, adaptive management, or monitoring. As we evolve an increasingly robust river delta strategy, we will likely find that [each delta](#) presents a unique set of constraints and opportunities.

Organizing Learning around Critical Dynamics

Rather than segregating delta ecosystems by scientific disciplines or lists of parameters, we propose a management framework that identifies a short set of critical dynamics to help organize our thinking. Each dynamic contains components, relationships and some compelling system scale phenomena that affect our management.

There are certainly other ways to diagram and define delta ecosystems.



There are considerable interactions among proposed ‘critical dynamics’. This framework is based on our repeated consultation with a cross section of the Puget Sound delta research community, and a review of the issues that decision makers and restoration practitioners have identified as important in their work. These dynamics provide a framework for summarizing existing knowledge, defining postulates that drive our current decision making, and ultimately for how we invest resources to improve the predictability of delta dynamics. These critical dynamics are not intended to replace more complex conceptual modelling of delta ecosystems, but to organize the interface between delta science and delta policy.

1. [Hydrodynamics and Channel Formation](#) – How the work of river flow, interacting with tides, creates and maintains a system of alluvial and tidal channels, and defines the physical and chemical character of the waters.
2. [Sediment Dynamics and Vegetation](#) – How the delta plain is built by accretion of sediment and debris which is variably colonized by vegetation.
3. [Biodiversity and Food Webs](#) – How the local biogeochemical environments of the delta develop trophic webs supporting dynamic and interacting populations of organisms.
4. [Salmonid Rearing Services](#) – How juvenile salmon linger within, and obtain critical services from the delta. This is a highly valued sub-topic within the larger topic of biodiversity and food webs.
5. [Human Social Dynamics](#) – How different groups of people perceive and gain benefit from the delta, and through attempting to exercise power over decision making and resources, affect the condition of the delta.
6. [Flood and drainage services](#) – How people living in the delta, cope with living at low elevations near big rivers by keeping sea and river water off the delta plain. This is a critical topic within the broader topic of human social dynamics.

Each of these critical dynamics contains a range of topics of interest to delta restoration practice. To make decisions in river deltas, we develop theories, postulates and assumptions about these dynamics. Our challenge here is to synthesize old knowledge, invest in new knowledge, integrate the two, and apply it to decision making.

Learning is a Project

Integrating research and restoration practice requires that we carefully select and design learning projects. We select research objectives by understanding available evidence and theory. We anticipate how decision making may be affected by new knowledge. We consider the duration and the risks of the work needed to acquire new knowledge. We remain responsive to the issues faced by projects, both those completed in the past, and those anticipated in the future.

Monitoring change over time is not necessarily the best tool for all learning. Natural experiments, extensive comparisons among multiple sites, space for time substitution (i.e. chronosequences) or opportunities unique to specific sites may provide the best opportunities to secure new knowledge. We must select tools that suit our purposes, and not prejudice our chances at success by limiting our learning methods.

As we define our learning objectives, and define the best learning tools, we define the human resources that we need to involve in restoration learning. These people may come from institutions not currently involved in restoration, with different goals and behaviors. A restoration learning program must develop a strategy for building and managing the social mechanisms necessary to complete the learning process.

Learning in Capital Programs

The [Estuary and Salmon Restoration Program](#) (ESRP) has made a commitment to integrating learning into project selection and funding. We view this activity as a necessary part of capital budget investment. Capital programs have a public trust obligation to insure that public investments result in the recovery of resilient ecosystems that provide valued ecosystem services. We use the scientific method to evaluate investments and manage risk.

Through the project selection process, negotiation of contractual terms, and review of deliverables, funding programs have a unique and unparalleled opportunity to integrate science and learning into ecosystem restoration on a dynamic and ongoing basis. Because of their scale and complexity, multiple funding sources commonly support each delta restoration effort. While this strategy is being initiated by the [Estuary and Salmon Restoration Program](#), it has the potential to support multiple programs. Coordination with additional funding partners more appropriately distributes what is a shared burden. Additional technical partners outside of ESRP are necessary to implement a fully functioning learning program.

Our implementation goal is to integrate learning into project development, so that we can maximize the opportunities for leveraging project work to improve our ability to restore river deltas. We propose three program elements:

- [A Core Monitoring Strategy](#) - where basic observations are consistently documented for all river delta projects.
- Implementation of Learning Projects - which requires definition of an RFP, proposal review, contract negotiation, and technical oversight.
- An Knowledge Synthesis Process - that integrates new evidence into a steadily evolving body of evidence, and provides feedbacks to both capital project decision making, and future learning project development.

Project Duration and Intensity

Different lines of investigation will require different levels of effort over time. Factors affecting the cost of investigations include how quickly the treatment elicits a response, the degree of variability among observations (both among sites and over

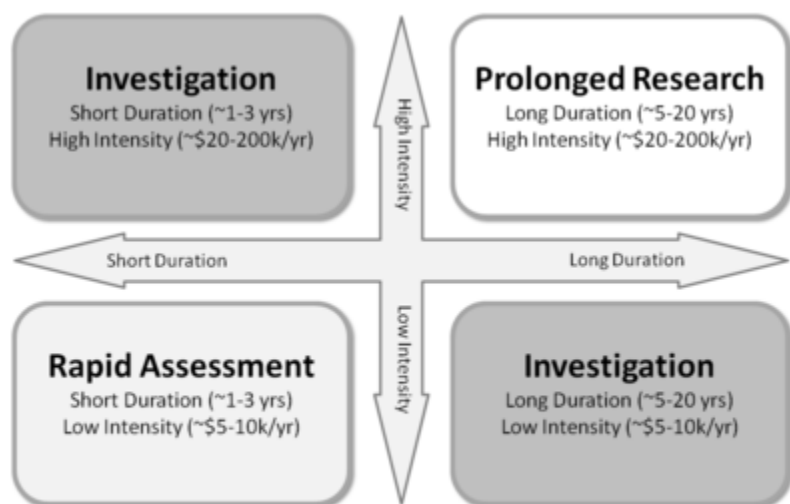


Figure 3 – Learning projects vary by duration and intensity of effort. This strategy is focused on

time), the scale of sampling necessary to characterize the response, the effort required to obtain a sample, and the number of other factors affecting the subject of study. In some cases investigation may require both intense and prolonged investigation. The cost of a learning project must be compared to the potential value and likelihood of generating decisive results.

The interval of observation under the mitigation model of observing change over time is frequently annual, but is rarely discussed. We assume that since change is rapid immediately following restoration, that we should measure things more frequently. Budgets are often shaped by the scope and duration of effort that an individual grant program will support. A prediction of the duration of effort necessary to obtain new or useful information is commonly lacking. Funding programs are notoriously inconsistent in their support for monitoring, creating a challenge for organizations attempting to maintain the capacity to do the work well.

Only by defining whole project costs and desired outcomes at the onset of a learning project can we begin to overcome these limitations and provide predictable public support for learning projects that maximize public benefits. By providing unpredictable funding for poorly defined investigations, public funders are undermining the very mechanisms for building knowledge, and justifying future investigations.

The [Estuary and Salmon Restoration Program](#) defines three levels of investigation. Protracted and intense research efforts are likely to divert more funds than sustainable for a program focused on capital projects. Some level of brief, low intensity investigation is necessary to insure a basic understanding of how projects are performing, and is discussed as part of our [Core Monitoring Strategy](#). Between these two extremes are two classes of learning project being considered. These are 1) projects that are short-lived, but require a relatively high intensity or extent of sampling, and 2) projects that require protracted observation to see effects, but where individual sampling events are relatively low cost. Both of these two classes of learning projects are considered as potential targets for investment.

Selecting Proposals for Investment

Rigorous and systematic observations are not guaranteed to improve the next restoration action, but there are few replacements for the benefits gained through scientific investigation. The breadth of potential investigations are staggering (for example, see [Gelfenbaum et al 2006](#)). Scientists each advocate for the research approach they value, often for very personal reasons. Academic institutions have very different cultural incentives and perspective than capital programs. Even while integration of on-the-ground work and research through adaptive management is near universally lauded, capital programs face a formidable task to integrate restoration and research.

We propose that three criteria describe the likelihood that a scientific study will provide a return on investment:

Importance

Not all topics directly relate to our ability to increase and sustain delta services. Important topics are anticipated to have a strong impact on the provision of services, where we cannot currently

estimate the effect of our choices due to lack of understanding of ecosystem dynamics. This later phrase is important. Just because a dynamic is important part of ecosystem function, does not mean it is important to how we conduct management.

Strong proposals have examined our ability to predict project outcomes, and has identified a lack of ability resulting in a risk of failure to achieve restoration goals.

Viability

Some investigations are more reliable than others, in that the factors being investigated are relatively simple to isolate and examine, and those factors strongly, consistently, and directly affect system behavior. By contrast some topics are mired in confounding factors, and are likely to require an intense and prolonged series of investigations to generate the evidence to affect decision making. While some of these topics are very important, so that we choose to begin work anyway, these opportunities must be weighed against the likelihood that useful information can be obtained given the limited resources of an individual program.

Strong projects have identified a pathway to obtaining new knowledge that is clear and where confidence can be demonstrated though a strong statistical understanding of the parameters in question, based on previous work in similar situations.

Policy Relevance

There are three critical junctures of decision making in capital programs: 1) In what locations should project development be supported, 2) how should we design to maximize cost/benefit and minimize risk of those projects, and 3) should the program continue on the same trajectory in the future. We should select learning projects that affect these decisions. Where issues arise infrequently, are exceedingly complex, or are very localized, policy change may be better achieved through political mechanisms, or systematic observation, rather than quantitative study.

Strong projects specifically identify how different study outcomes might directly affect policies and decisions that affect future efforts.

The Importance of Defining Working Postulates

To organize our learning effort, we have identified a set of six critical dynamics. Our understanding of these dynamics is built of a network of axioms and postulates based on a body of evidence and speculation. The postulates represent ideas about how deltas work, around which we have some uncertainty, as compared to axioms, where we are confident in our understanding due to a level of research and refinement (following [Ford 2000](#)).

As we examine the dynamics of delta ecosystems, we are looking for specific postulates that fit our selection criteria of importance, viability and policy relevance. We are looking within our network of theory for where a lack of evidence creates a vulnerability, that is matched with a clear opportunity for learning that will change policy.

This process begins by making explicit, our postulates about how restoration works. These postulates are often unspoken, or are briefly and imprecisely stated in the thick of grant application text. By making our postulates written, public, and explicit we achieve the following goals:

1. We define a stable conceptual landscape that can be subjected to critique, countervailing evidence, or alternative explanations.
2. We create a written record of propositions and evidence, accessible to a wider audience, that can be revisited and refined over time as new evidence emerges.
3. By holding up a set of postulates, at the level of the funding program, we take some responsibility for making predictions in a way that encourages implementers to evaluate, test, and improve understanding without having to defend what are collective assumptions, while at the same time requiring implementers to be responsible to a prevailing understanding of delta ecosystems.

To fully develop this element of the [River Delta Adaptive Management Strategy](#) we propose using this wiki to maximize both participation and transparency. The following set of topics, organized by our critical dynamics represents that initial population of topics where we believe a learning opportunity may exist:

Topics Describing Critical Delta Dynamics	High Uncertainty Topics for Adaptive Management
Delta hydrodynamics and channels	• Delta restoration and farm system function • Development of tidal channels following restoration • Fringing marsh resilience, wave attenuation and flood management • Puget Sound Tidal Wetland Barrier Removal Planning • Rate of channel development • Tidal Channel Reference Model
Delta sediment dynamics and vegetation	• Delta plain accretion rate among systems compared to sea level rise • Distributary configuration effects on delta sediment deposition • Effects of relict levees on sediment and debris deposition in delta systems • Factors preventing development of productive delta marsh vegetation • Fringing marsh resilience, wave attenuation and flood management

	• Viability of assisted vs. unassisted development of tidal fresh swamp
Delta biodiversity and food webs	• Delta Management for Waterfowl • Effects of introduced species on delta functions • Factors affecting long term composition and productivity of delta invertebrate communities • Potential extent, function, and requirements for beaver habitat modification in delta landscapes • Relative use of delta landscapes by valued bird populations
Delta utilization by salmon	• Effects of delta landscape connectivity on realized function for juvenile salmon • Effects of local delta habitat structure on salmonid carrying capacity • Relative importance of wetland composition on delta carrying capacity for juvenile salmonids • Tide gate effects analysis
Delta social dynamics	• Delta Management for Waterfowl • Influence of ecosystem service quantification on stakeholder preferences around restoration
Delta flood and drainage	No topics are being developed. Drainage and flood effects are evaluated as part of the 'High Risk Project' component of the core monitoring strategy

Barriers to Effective Adaptive Management

[Beover \(2008\)](#), in support of [PSNERP](#), interviewed staff at three ecosystem restoration programs--CalFed, Louisiana Coastal Area, and Everglades--to evaluate barriers to adaptive management in ecosystem restoration. He identified seven candid and practical problems derived from first hand experience in ecosystem management. We acknowledge and describe our strategy in response to each problem:

1. Scientists are held responsible for success, but lack the resources and authority to implement, and are avoided on politically sensitive issues.

We anticipate a system of checks and balances between the science and management communities. Shifting all power to an academic science community does not assuredly increase the effectiveness of management. We propose an open and internet-based forum in which scientists and managers define the sources of restoration uncertainty. We define and analyze

the scope of collective need prior to funding. By selecting learning projects from a suite of opportunities, funding programs assume responsibility for success, but are informed by the stated needs of a community of practice. By allowing the science community to define risk in a transparent forum we reduce the risk of politicized avoidance.

2. Few dedicated staff actually focus their work on management of adaptive management--effort is diffuse and split among many part time staff. Staff turnover and unclear points of contact inhibit continuity.

At this point, staffing is provided by [ESRP](#) and [NOAA Restoration Center](#), and is integrated into a capital program budget. By integrating peer review processes into project selection, we hope to minimize and decentralize management labor, while creating a vehicle for distributing knowledge. By building a transparent and public body of evidence, linked to learning targets, we hope to develop a system of mutual benefit that maximizes resilience, while minimizing any risk of discontinuity caused by weaknesses in individual organizations. Long term staffing is a critical vulnerability, and diversifying beyond [ESRP](#) support is important. Development of overlapping fellowship positions within university departments, funded by multiple delta restoration partners, may be cost-effective tool for both increasing academic involvement and maintaining continuity.

3. System models are not designed to address the uncertainties that are the subject of adaptive management.

The program anticipates development of simple nimble models that support local planning and prediction (for example, the [Delta tidal channel reference model](#)). Given our scale of resources we anticipate development of a series of studies, rather than development of a singular, inflexible, and cumbersome decision support model. Our objective is to identify sources of risk, and develop models as necessary to explain those risks, which places the focus of quantitative work appropriately on those portions of the system where we perceive vulnerability. By diversifying model generation, we will need to evaluate risks related to loss of 'interoperability'. The community of practice is small enough that these risks can be overcome with increased communications.

4. Established monitoring competes with new monitoring, and monitoring may or may not be oriented to resolve the questions identified as most important to adaptive management.

We minimize programmatic monitoring under our [Core Monitoring Strategy](#), to maximize resources available for learning projects. These projects are of limited duration to achieve specific objectives, reducing the entrenchment of monitoring interest groups. The program will need to guard carefully against systematic underestimation of the effort required to generate useful new knowledge, which creates a compulsion to continue funding indefinitely for fear of losing sunk costs. This is best managed through rigorous evaluation and scoping at the onset of a project. This requires adequate independent technical review during selection and contract negotiation, which is currently lacking at [ESRP](#). Development of a blind and anonymous peer review system is anticipated to provide value. We will need to reinforce a feedback loop that updates the knowledge base of our peer review community as new evidence is developed.

5. FACA requirements can inhibit extensive stakeholder involvement.

This concern primarily develops where many players are attempting to affect large federal funding decisions. We anticipate a system where implementation is broken down into a series of discrete investments. Funding decisions are independent and autonomous, but supported by a collectivized and competitive, criteria-based and peer-reviewed processes that provides decision support, consistent with the public interest, and avoiding a conflict of interest.

6. Cash flow to support work creates delays and diversion from planned adaptive management objectives.

Project selection criteria focus learning efforts on obtaining increments of evidence that are suited to restoration project funding sources. Continuity is maintained by development of a long term adaptive management agenda. This approach does preclude monolithic intensive and long term efforts. This simplification and narrowing of learning focus may be a necessary step in turning adaptive management from a concept into a reality. Because our learning goals and risks are diverse, we anticipate that we will be better able to adapt to shifting funding while maintaining and integrating incremental gains in knowledge.

7. Absence of institutional recognition or reward to successful implementation of AM. AM is not a necessary part of any agency's work.

Our aim is to use existing resources to demonstrate the value of targeted restoration research to stakeholders who are invested in restoration outcomes. We assume that stakeholders will value new evidence and information. If we are successful, we will increase the perceived value of restoration research. In this way we are not focussed on adaptive management as an activity, but rather on providing solutions through adaptive management to recognized problems, while simultaneously increasing recognition of real problems. We anticipate that if we deliver both clarity of risks, and value through adaptive management, we will gain a constituency that will support the work.

The Beaver's analysis suggests that a short term need for this strategy is to diversify funding, and reduce dependency on the [ESRP](#) program as the sole source of financial and political support. This will require both specific collaboration between key partners, and development of a broad stakeholder community that can perceive a benefit to coordination of learning in delta restoration. To the extent that we successfully develop broadly participatory mechanisms, and diverse patronage, we will increase the odds of developing a sustained learning community.

Building Continuity in Learning

Our conceptual framework identifies a set of topics that describe what we know and don't know about delta restoration. This system of topics is described [on our delta strategy page](#). This open source information sharing environment allows identified users to post documents and collaboratively edit text. Development of wiki content will become a contract requirement of grants. Participation is further incentivised as wiki content becomes a source of best available evidence and a marketplace of ideas, informing future funding decisions.

Each cycle of solicitation, review, selection and implementation further refines these topics in a transparent web-based format. Any partner is free to add additional sources of evidence and improve synthesis. These wiki articles reflect our best available understanding of delta restoration and so inform our technical review and contract negotiation. Partners that help us increase the rigor of our synthesis are consequently raising the bar for all competitors in the learning project selection process.

Using a highly accessible wiki increases the potential for broad stakeholder awareness of restoration practice and restoration science. While a more open information environment may be uncomfortable, building broader stakeholder engagement through information sharing may strengthen our ability to restore ecosystem services over the next generation at a meaningful scale. In addition, an open information environment increases both the opportunity for collaboration, and accountability for advancing project work consistent with working in the public interest.

Learning Project Selection and Peer Oversight

There are four practical functions to develop within the ESRP program to implement this strategy:

1. development of a learning project requests for proposals,
2. evaluating which learning proposals best meet criteria,
3. developing a scope of work that maximizes public benefits, and
4. integrating the results of a learning project into a shared body of evidence that informs future decision making.

These activities will need to occur either through increasing ESRP staffing, collaboration with additional partners, or delegation of these tasks to project proponents through contracting.

1. RFP Development

We select proposals on a biennial basis that reflect the best opportunity to advance learning. The best opportunities depend on a confluence of factors: availability of an investigator, overlap with imminent project work, incorporation of recent findings into a new investigation, and leveraging of other resources. For these reasons, we anticipate that RFPs will continue to solicit a range of proposals.

However, now that we are managing an information framework, we expect RFPs to solicit proposals directly related to this Delta Strategy, that integrate the evidence and assumptions described on topic pages. Learning projects that propose specific advances in knowledge, within a clear time frame, that will have a described impact of specific decisions will be considered. Our core monitoring strategy will be used to guide all other investments in monitoring.

Between RFPs ESRP staff and partners at the Salish Sea Restoration, will work to identify cost-effective opportunities to expand and refine topic pages of interest to delta restoration so

that they organize and present the best available evidence and synthesis. Potential applications are encouraged to participate in this transparent discussion of delta ecosystem dynamics. We anticipate that this wiki will provide a strong basis for technical proposal review.

2. Proposal Review

Proposal review is focused on our three criteria of importance, viability and policy relevance. Each criterion requires a different perspective on a proposed learning project. The potential policy relevance of the proposal is best analyzed by those who are involved in making policy. The importance of a proposal requires understanding of existing sources of scientific evidence. Viability requires specialized practical experience in ecological research and biostatistics within a specific arena.

[ESRP](#) has relied on community-based peer-review for project ranking. We anticipate that learning proposals may require an even broader peer community, with more technical expertise in delta ecosystems. This expansion of peer review based on ecosystem sites, may increase the rigor of restoration and protection proposal review. Anonymous peer-review may become an important part of our proposal review process.

3. Scope of Work Critique

At the point of developing a scope of work, the program has already committed to investing in a course of investigation. Scope of work critique is focussed on ensuring that work is done in a transparent manner, that engages the stakeholder base necessary to ensure that scientific investigation connects to policy at later stages of the project. ESRP staff have limited capacity to shepherd learning projects, and restoration projects commonly are vetted through regional coordination organizations, like the Lead Entity.

For these reasons, ESRP may interject additional tasks into a learning project scope, requiring additional peer review and communication tasks. These tasks may require engagement of independent review to enhance transparency and quality of work, without compromising an investigator's ability to manage project scope. Specific tasks around posting and communication of results and integration of new evidence, using the Salish Sea Restoration platform, are described in our [River Delta Adaptive Management Strategy/Learning Project Scope of Work Template](#).

4. Publications and Synthesis of Results

The Salish Sea Restoration site provides an opportunity to make projects visible and accessible. Learning Project proponents will be required to develop a learning project [effort](#) page, and upload key documents. These products can then be cited in an appropriate topic page, where it may be considered in future decision making.

To actually review and weigh evidence, and integrate evidence into a revision of restoration postulates, is demanding work. This work has not to date been a strong part of the restoration process, perhaps in some cases to the detriment of restoration effectiveness. However, public critique and analysis is uncomfortable, and the sometimes politically controversial processes of

restoration have encouraged tight management of information, let alone speculation. We anticipate this will be an area of growth and development, that will not always be predictable or comfortable. This may be an opportunity to better integrate the academic community, that is more practiced at critique and synthesis, and less affected by political risk.

A Note on Comprehensive System Monitoring

Skagit, Snohomish and Nisqually deltas have each proposed large scale systematic monitoring of delta ecosystems. We recognize that this scale and intensity of effort may provide unique insight into the dynamics of delta ecosystems, and ultimately may provide the only viable evidence to support important questions about ecosystem restoration.

The level of funding necessary to sustain the robust implementation of these programs is beyond the ability of the ESRP program to fund, and program staffing does not have the capacity to evaluate whether a prolonged and intensive approach is providing a robust and efficient pathway to new knowledge.

We strongly support the development of local-state-federal-academic partnership that can prioritize and consistently fund whole delta monitoring efforts. The development of these efforts provide an irreplaceable context for considering the findings of project monitoring or more focused investigations. For example, work on evaluating tide gates has benefited substantively from the ongoing [Skagit Delta Intensively Monitored Watershed Project](#). Development of coordinated approaches to comprehensive system monitoring is the logical next step to increasing learning. We do not address that need here.

Core Monitoring Strategy

Given the scale of public investment in delta restoration, we require a record of restoration project work that allows for some verification of the scale of restoration effects. To complete extensive monitoring of every project, site, and system over time would require an unprecedented expansion of public spending authority, and may not be cost/effective given the cost of extensive monitoring compared to the likelihood of generating actionable new knowledge. In addition, a monitoring change over time approach to learning may fail to resolve issues that require comparison among multiple sites, evaluation of a site in the context of the delta system, or comparison among systems.

Therefore [ESRP](#) does not implement extensive monitoring at every project site. Instead we apply research methods specifically designed to achieve our learning objectives. However, some level of rapid assessment at every site is useful for verifying the general effects of restoration, and identifying issues that deserve more aggressive investigation. Thus we propose a minimum core monitoring effort be undertaken at every delta restoration site that alters hydrodynamics.

To achieve this goal we aim to optimize sample accuracy, while reducing the frequency and intensity of sampling to only that necessary for the desired analyses. We focus on low-cost and

well stratified sampling approaches, and limit parameter estimates to low variability measures that are critical drivers of delta dynamics. In addition, we encourage systematic qualitative work to build a strong basis for speculation to define future work.

Some projects may poorly fit the methods we recommend. Those projects should be identified early in project selection. Development of an evaluation approach can then be integrated into design tasks, using the [River Delta Adaptive Management Strategy](#) as a framework. Special types of projects, with known and unique risks are discussed in the section on [high risk projects](#) and recommended for additional study design.

This core monitoring strategy will be integrated into ESRP's project selection and contracting process. Early in project review, projects are flagged as appropriate for core monitoring, and evaluated for risks. Each flagged project has core monitoring tasks integrated into their contract, with projects entering the ESRP program late in their development, responsible for rapidly completing any previously required tasks. Out-year data collection and analysis is negotiated during the construction phase, and may be implemented through the ESRP portfolio process, which allows funded ESRP actions to receive supplemental funding for approved tasks through a streamlined application process following competitive selection of a selected alternative. Tasks are either completed by the project proponent, or are subcontracted to a third party.

Our core monitoring strategy focuses observations on two critical dynamics described in our [Delta Ecosystem Model](#): 1) Hydrodynamics and channels, and 2) Sediment dynamics and vegetation.

Component	Method	Design	Analysis
Hydrodynamics and Channel Formation			
Benchmark	Elevation monument established on site and located relative to local tidal parameters and NAVD88	Location is stable, convenient and easy to relocate - verify elevation using RTK prior to survey season	Use benchmark as basis for elevation surveys to place analysis within the local tidal frame.
Project Extent and Elevation Zonation	Delineate project extent using aerial photography - use LIDAR or other topographic data to define site zones relative to local tidal parameters	existing models] where feasible	Extent polygon is shared with ESRP and used as a basis for accounting - elevation zones are used to stratify sediment and vegetation sampling - DEMs are integrated into updated regional models
Channel feature baseline and change	Channel features are delineated using aerial imagery and DEMs - longitudinal survey and outlet cross section are made of excavated and relict channels - Tidal basin or island area is estimated	Baseline established following construction - repeated after five flood seasons - identify issues for systematic subjective observation	Compare geometric parameters to baseline and available delta tidal channel reference models .

Water level verification	One or more water level data logger with control for atmospheric pressure	one year following construction with reference site - select points to represent potential sources of constriction and range of tidal connectivity within site - tie to benchmark - before construction data critical for sites with more subtle change in tidal inundation	compare site levels to control levels before and after construction, corrected for atmospheric pressure and compared to tidal datum.
Sediment Dynamics and Vegetation			
Sediment accretion	Sediment stakes and collection plates/marker horizons randomly located along Mean Tide (or appropriate) contour with exclusion criteria, and stratification by distance from distributary	Established 1 year after reconnection - re-sampled after 5 flood seasons - include references that represent the range of deposition in the system - include redundancy in anticipation of lost stations - include specific locations and predictions in systematic qualitative observations	Calculate annual accretion rate compared to reference - consider local and regional discharge record to support increased understanding of relative sediment budget among systems
Vegetation recruitment	Delineate observable vegetation zones on aerial photos and intersect with high marsh/low marsh elevation zones and any planting zones - relative dominance and vegetation height in plots stratified by composite zones to achieve random stratified representative sample	single sample in fifth full growing season after restoration to identify species frequency and cover by zone - add baseline and first full growing season survey where complete vegetation turnover not anticipated - include specific locations and predictions in systematic qualitative monitoring	Compare mean cover and composition among zones, where baseline established observe both shift in zone area and zone composition, compare to model predictions and site predictions based on reference vegetation or regional models established during design.
Out planting documentation	Delineate planting zone polygon in GIS - document stock, quantity, and species	Record immediately during and following installation season, with updates at each subsequent installation season - include specific locations and predictions in systematic qualitative monitoring	Planting extent use as zone in vegetation recruitment analysis.
Systematic Qualitative Monitoring	Narrative and photographic observation of site development based on specific speculation about dynamics and driving factors	sites selected subjectively to reflect predictions and questions specified during design	Minimum of Winter/Summer biannual photos and narrative organized by observation theme and location, with cumulative observations over time made publicly available

Hydrodynamics and Channel Formation

Recovery of historical functions is most likely with restoration of hydrology and channels. Channel development provides a primary metric for indicating recovery of function for fish. Elevation mapping relative to tidal range, and establishing that restored tidal range is a critical tool for evaluation of sediment dynamics and vegetation.

Benchmarks

Each site will establish an appropriately sited benchmark monument surveyed to a known elevation using NAVD88. The nearest appropriate tidal recording station should be selected for the purpose of relating absolute site topography (NAVD88) to tidal datum.

Project Extent and Elevation Zonation

Site topography is necessary for delineation of elevation zones. Elevation zones can be used to predict fish access and vegetation development, and are expected to affect accretion rate. Pre-construction LIDAR data are available to describe most Puget Sound Deltas. LIDAR data can be converted to elevation zones for the purpose of stratifying sampling and describing the area of delta plain under restoration. Where LIDAR topography is not available, either the project site should be enrolled in a collaborative over-flight, or point topographic surveys should be converted into a NAVD88 raster layer, which can be in turn coded to reflect elevation zones consistent with the selected local tidal datum. Initial work is proposed by the [Delta metrics project](#).

The extent of the project area should be defined by a GIS polygon to include all areas where earthwork has changed elevation (old dike footprints) as well as all areas where hydrology has been modified through reconnection to riverine or tidal flows, including the extent of the 100 year floodplain or extreme high tide. This project footprint is shared by [ESRP](#) with the [Delta metrics project](#) to provide metrics that describe the impact of the project compared to historical and current tidal flow.

Channel feature baseline and change

Using a high resolution aerial photography in a GIS environment delineate all channel features within the project extent. Delineation consists of polygons defined by the channel edge, and a longitudinal survey of the channel thalweg. A cross section survey should be established at the predicted channel outlet, and perhaps at additional point within the channel system where specific uncertainties are identified. Survey elevations should be tied to a site benchmark and thereby be available in either NAVD88 or relative to the tidal frame.

This initial work should be completed immediately following construction, and before the winter flood season. In subsequent years, a systematic qualitative monitoring strategy should be developed, using photopoints and narrative notes and published on the effort page.

4 full water years following construction, the channel delineation survey should be replicated. Record any observations of barriers to erosion (root mass, gravel, or compacted soils). Either island area (where possible) or an estimated tidal basin area, is delineated using best professional judgment.

The predicted range of equilibrium channel geometry, using the [delta tidal channel reference model](#), is generated from the estimated tidal basin area, and is compared to measured channel geometry, to describe progress toward formation of natural equilibrium channels, in terms of

percent recovery. Channels with very different configurations may have similar metrics, and so parity in metrics may or may not indicate parity in all functions.

Qualitative notes may be as significant, or more significant in defining issues that are integrated into our synthesis of the [development of tidal channels following restoration](#). Results should be published on the project effort page, and evidence integrated into the appropriate topic pages.

Water Level Verification

Water depth, salinity, and temperature within the site should be monitored for one year using a continuous data logger before reconnection of hydrology, and one year following reconnection of hydrology. Monitoring should occur at a relatively low elevation to, at minimum, capture all fluctuation of water levels above mean tide, and the logger should be surveyed relative to the site benchmark to position all water depth readings relative to NAVD88 elevation and the tidal frame. Depending on the complexity and size of the site, additional sample locations could be established to describe the range of salinity regime, muting of full tidal range due to interaction with freshwater flows, or tidal constriction.

Tidal observations for the same one year time period should be retrieved from a local tidal datum (or best available prediction of local tidal datum) and used for comparison. Local water data are compared to the tidal record, and are used to generate a local correction factor that is then used to establish three elevation zones relative to the tidal frame, and are used to support monitoring of vegetation and sediment accretion. Observations here may modify our assumptions about [delta hydrodynamics](#).

Sediment Dynamics and Vegetation

The objective of the core monitoring of sediment dynamics and vegetation is to estimate the rate at which sediment is entering a site (in volume/year at the selected elevation), and to determine whether vegetation establishment is generally occurring in a manner consistent with seed availability, elevation, and salinity regime. While vegetation development rate may vary, we are primarily interested in whether the range of species anticipated at the site is establishing within those elevation zones where rapid plant recruitment is expected (between MHW and XHW). Aerial photography is used to describe patterns of early recruitment, and random sampling within elevation and observed vegetation zones are combined with narrative observations linked to plot photos to characterize early establishment.

The evaluation of change in elevation through use of sediment elevation tables (SETs) which allow for comparison of accretion, shallow, and deep subsidence to elevation change requires careful development of a study design and sampling strategy and is beyond core monitoring, but may be pursued at some sites where evaluation of subsidence and accretion is urgent. Sediment accretion estimates focus on use of sediment plates and marker horizons in association with sediment stakes.

Sediment Accretion

Site micro-topography is known to adjust both up and down during initial site development, with both erosion and deposition occurring across the site. Local topography may affect this initial adjustment of sediment elevation, with localized depressions collecting sediment. Sediment deposition rate is anticipated to both be a function of elevation (the proportion of time that a site is exposed to sediment laden water), proximity to river inputs, and the effects of vegetation or other obstructions which slows velocity (for discussion see [Delta sediment dynamics and vegetation](#)). Wave energy may re-suspend sediment or concentrate sediment deposition. The purpose of this measure is to generally characterize the degree to which sediment is entering the site.

Our basic sediment accretion observation should attempt to avoid confounding factors to generate a relatively precise measure of sediment inputs. We recommend sediment measurements all be taken along a mean tide (MT) contour (as appropriate), with stations distributed across a 'distance from river flow' gradient should one exist. Sites should avoid areas of woody debris to minimize effects of surface roughness. Sites should avoid local topographic lows that impound water between tidal cycles, and any areas of channel formation. To assist sample site selection, we recommend that site selection occur 1 year after restoration of tidal flow, so that tidal water drainage patterns can be used to assist with station selection.

We recommend a sediment stake method for evaluating sediment accretion at a new site. A straight edge is placed level between two permanent monuments (t-posts), and mean elevation is measured using a suspended weight and tape measure. Monuments can be destroyed by flotsam or vandalism, and so posts should be low visibility, and additional sites should be established to account for a loss of 10-20% of monuments. Uniquely identifying and documenting the position of each post of a pair allows for one post to be replaced should it be damaged, by referencing the position of its partner.

To complement the sediment stake approach, sediment plates and placement of a marker layer, relative to the stakes (and protected from trampling) can be used to verify deposition rate.

Not using a SET decreases the accuracy of measurement, and so a period of time should be allowed to pass before repeated measurements to reduce the error relative to accretion rate. We recommend four full water years between establishment and measurement to produce a robust calculation of mean accretion rate, a period generally corresponding to proposed vegetation and channel measurements.

We currently lack the data necessary to develop a robust rate estimate for a site, and are lacking the analysis to place the rate estimate into a regional context. Some assessments of mean sea level rise, corrected for local isostatic rebound rates are available. Little information about local subsidence is available. Our ability to evaluate sediment input will improve over time. The majority of new sediment deposition is anticipated to occur during large river flood events which may not occur every year. The record of river flow should be retrieved over the deposition period, and used to compare the sampling period to the period of record to determine if rates observed during the sampling period are likely to be typical.

These observations may result in speculation which leads to more robust studies to evaluate sediment dynamics and particular systems, where there are risks to restoration effectiveness resulting from low sediment accretion rates (see [Delta sediment dynamics and vegetation](#)).

Natural Vegetation Recruitment

Vegetation establishment is not continuous over a site. Initial seedling recruitment may be higher based on seasonal wrack deposition patterns which may include floating seed. The relative dominance of species in natural vegetation is strongly linked to elevation and salinity. The objective of core monitoring is to determine whether species anticipated to form the mature vegetation, given salinity and elevation, are establishing within the site.

Evaluation begins with a prediction of species anticipated to provide the greatest proportion of primary production at the site. In salt marsh environments this is typically *Distichlis* and *Salicornia*. In Transition environments this may shift to *Carex* and *Schoenoplectus*, perhaps including *Myrica gale* in some systems. Freshwater systems may be dominated by *Typhus*, or at higher elevations, by shrublands dominated by *Rosa*, *Lonicera*, *Salix*, *Malus*, or *Rubus* with a potential canopy of *Picea* *Populus*, or *Alnus*. Prediction should be based on elevation zones and salinity identified during core hydrodynamics monitoring, and consideration of local vegetation patterns and composition.

The strong influence of elevation on vegetation requires stratification of sampling by elevation to develop robust estimates of cover, and discussion of the species composition results. We propose a random but stratified representative sample as the most useful tool for describing restoration site condition. One goal of any vegetation sampling strategy is to establish an easily repeated route that allows for rapid sampling of a large representative sample within three elevation zones. The first zone is between Mean Tide and MHW--the lowest extent of vegetation. The second zone is between MHW and MHHW, the elevations anticipated to be dominated by low marsh. The Second zone of interest is between MHHW and Extreme tide, where high marsh and perhaps woody vegetation are expected to establish. This requires delineation of these elevation zones based on the hydrodynamic measures described above, and then definition of a set of random sample locations distributed among each of the sample zones (likely using a baseline and offset approach), imprecision in individual sample site location is acceptable as long as it is not biased, as the samples collectively produce a robust representative sample of cover and composition for the whole site. This requires a rapid method for describing sampling sites (likely using a simplified measure of relative abundance, and a single 'height of vegetation' measure, and a single sediment characterization).

The goal of this approach is not detect year to year change along a transect, but rather to concentrate quantitative sampling to establish a single strong snapshot of site condition stratified by elevation. Subjective qualitative methods are anticipated to provide observations of the many subtle dynamics in vegetation development that are unlikely to be detected even by the coarse parameters developed by annual transect surveys.

A single sample may occur in the middle of the fourth full growing season after hydrologic reconnection, to characterize the wave of establishment anticipated following hydrologic

reconnection. Prior to field work, best professional judgment and a high resolution aerial photograph from the previous summer are used to delineate zones of similar vegetation appearance. Where clear boundaries between vegetation zones cannot be observed, then elevation zones are used alone. Sampling locations are randomly identified to generate a representative sample of each vegetation zone that occupies more than 10% of the total area of the two elevation zones described above.

During sampling, photo points are established that best characterize the site. To the extent possible, simple directions are used (e.g. bearing 0 degrees North). The cover and composition of vegetation are estimated visually, and any observations of pattern, demographics, autecology, or synecology are recorded.

On many sites, the pre-restoration vegetation may have little bearing on the post restoration vegetation due to the radical change from altered hydrology and salinity. Where vegetation change is anticipated to be more subtle, and the degree of change has significant management implications, additional sampling events may occur prior to construction, and in the middle of the first full growing seasons after restoration of tidal flow, to describe a baseline condition and the immediate effects of altered hydrology.

We strongly encourage additional observations, using a systematic qualitative approach, incorporating images and narrative, and incorporating repeated observations beyond the quantitative sampling event. Development of a more involved strategy attempting to isolate other controlling factors or detect change in community composition over time is beyond the scope of this core monitoring.

Quantitative analysis produces a summary of site vegetation in terms of zone coverage, and zone composition four years after restoration, which can be discussed in comparison to predictions of vegetation development based on local seed source, site elevation, salinity, and regional research and modeling.

Out Planting Survival

For each planting footprint, the quantity, species, stock type (e.g. 1 gal potted or 2-1 bare-root) should be documented. A new planting footprint should be developed for any area where composition or density or planting is substantively different. Planting footprint should be documented as a shapefile or KMZ file. Post planting evaluation of survival is optional, and may follow any protocol that generates proportion of survival by species. Results of survival should be presented by species by planting zone, and discussed in terms of observed site conditions, and any spatial pattern of survival or speculation related to the details of planting or stock condition. Evaluation of out planting survival, where the study attempts to isolate factors affecting survival and growth are beyond the scope of core monitoring.

Dynamics Reserved for Learning Projects

The [remaining critical delta dynamics](#) are not currently addressed by core monitoring. We believe these topics require an intensity and duration of effort, and a precision of design, poorly

suited to generalized methods and protocols. These topics will be addressed through [development of learning projects](#).

Salmonid rearing services

Effective observation of salmonid use and realized function requires development of a detailed measurement and analysis strategy that is beyond the scope of core monitoring. Because robust understanding of fish benefits from restoration are so central to evaluating restoration effects, we recommend reserving all available fish sampling funds to support rigorous investigations that are developed to systematically target critical uncertainties, and allow for prediction of fish benefits from site and system structure.

Biodiversity and food web development

Generally where sediment accretion is present, and predicted vegetation has begun to establish, and there is not clear impediment to fish access, we assume that food webs will develop parity with reference sites over time with a similar elevation, salinity regime and level of connectivity. Given the high spatial and temporal variability in invertebrate communities, and the high mobility of vertebrate communities, we don't propose these activities as part of our core monitoring strategy.

Flood and drainage services

Given the unique character of flood and drainage infrastructure, standard protocols are poorly suited to evaluating changes in flood or drainage services. Projects that are anticipated to affect drainage of adjacent agricultural lands (either beneficially or adversely) are considered a high risk project type, and are recommended for site specific before-after control-impact monitoring strategy to evaluate how restoration efforts affect groundwater and surface water levels over time.

Human social dynamics

A core strategy for evaluating project effects on human social dynamics has not been developed and is anticipated to exceed the capacity of a core project monitoring strategy. This reflects a generally weak engagement of social science, or for that matter public communication, in delta restoration work, with the vast majority of effort consumed by reacting to social conflicts during design and permitting.

High Risk Projects

Certain kinds of actions are anticipated to produce a risk of unintended effects or constrained benefits. These actions may deserve additional analysis. For example, projects which depend on a tide gate for hydrologic reconnection may constrain fish passage in ways that have not been rigorously evaluated (see [Lyons & Ramsey 2013](#)). Ideally high risk projects are associated

with a developed [river delta adaptive management topic](#), and actions are enrolled in ongoing efforts to increase the predictability of restoration outcomes.

The following project types are recommended for additional consideration. Identification of potential risk should be part of project evaluation during the design phase. An analytical method would be developed during project design. Additional risk factors should be considered and proposed during project development, considering [our adaptive management criteria](#)

Tide Gate Risks

Where construction of setback levees is not feasible, the perpetual management of hydrology and fish passage using tide gates may be an attractive partial restoration solution. Tide gate effects on ecological restoration goals are highly variable depending on the setting, species, and characteristics of the control structure (see topic page ([tide gate effects on salmonid passage and utilization](#))). Given the capital and operating costs of these systems, and potential effects on restoration objectives, continued evaluation of tide gates on a project by project basis is necessary to justify their use as a restoration tool.

We anticipate that monitoring will involve development of a robust experimental design that develops an adequate reference site, differentiates among tide gate effects on different species, monitors the physical operation of the gate over time, particularly in association with sampling periods, and considers year to year variation in out-migration as a factor potentially affecting local abundance of target species.

Limited Breach Risks

Where hydrologic reconnection is considered the primary ecological effect, a project may complete only limited breaching of dikes and levees just sufficient to restore unmuted tidal hydrology. In some cases, levee retention may be driven by social interests in maintaining access for recreation or maintenance. Remnant dikes and levees may continue to affect routing of sediment and debris and biota by affecting river flood flow. The effect of remnant dikes and levees on ecosystem dynamics and services is poorly understood, and creates an anomaly within the delta landscape. Despite potential impacts of hydrodynamics, some have argued that relict levees provide platforms for the development of forest vegetation which increases ecosystem services through biotic inputs and shading.

Projects which must maintain anthropogenic structures in the delta plain that are anticipated to affect river flow should be considered as potential learning opportunities. The potential effects of these structures on system dynamics and services should be explicitly predicted, and a monitoring approach developed to test these predictions. Not all settings may allow for robust comparison among sites necessary to detect the effects of relict levees and dikes.

Downstream Scour Risks

Projects that modify the distribution of river flood flow, or augment river flood flow by increasing tidal prism, may increase the maximum discharge of delta ebb water within a constrained

channel during river flood, increasing velocity, and the potential for scour erosion. While the velocities of delta hydraulics are typically low, delta sediments are highly erodible, and so where infrastructure might be threatened by a change in channel size downstream of a restoration project, the risks should be identified, possibly leading to simple and direct monitoring and management planning.

Agricultural Drainage Risks

Restoration of tidal flow may create mounding of groundwater, increasing saturation of surface soil on adjacent agricultural lands. Modification of drainage structures and flow pathways to allow for restoration may similarly affect agricultural land drainage. Soil drainage, particularly in spring can strongly affect the ability to till and plant, and so can affect the viability of agricultural businesses. Even where project work is not a factor affecting agricultural operations, the perception of effect can impair future restoration efforts.

Longshore drift dynamics can cause movement of material at the outlet of tidal channels draining a restoration site and adjacent agricultural land. This shoaling may be triggered by modification of seasonal or ebb tide discharge, or may have no relation to restoration actions. These changes in the delta plain can affect the function of upstream drainage infrastructure. Again both actual culpability and perception are intertwined.

Project design is the point at which potential impacts on agriculture drainage should be considered, and integrated into the assessment, monitoring and management strategies. Without baseline observations of ground water behavior or current drainage pathways, post construction monitoring is insufficient to establish the character or cause of a perceived problem. Year to year groundwater variation requires that monitoring of agricultural drainage consider yearly variation in rainfall as a factor affecting groundwater dynamics.

Sediment Contamination Risks

Some sites may be subject to chronic or acute sediment contamination due to point or non-point sources of pollution. Common sources are from industrial activities, redistribution of historical industrial contamination, current stormwater discharge from urbanizing and agricultural sites likely containing oils, fertilizers, pesticides, heavy metals and a range of poorly understood biologically active substances.

Establishing the impact from pollution requires establishment of a baseline site conditions. Future impacts can be compared to baseline conditions to establish that a pollution related injury may have occurred. Without a baseline, it is very difficult to establish the source or timing of a pollution injury.

A site with a high potential for pollution related degradation should consider two critical questions: 1) what are the likely sources and types of pollution, and 2) what management decision would be triggered through establishment of pollution impacts? If there are clear risks of pollution over time, and there are understood management decisions that may hinge on

detecting those impacts, then a project pollution management plan should be developed and implemented as part of design work and stewardship planning.

Systematic Qualitative Observation

Our plan that quantitative monitoring will provide scientifically robust evidence that helps us make our next decision, may not work as well as we like. A large number of factors are at work in ecological systems. Ecological research often attempts to use a large and well designed sampling strategy to identify factors that commonly or strongly affect outcome. Repeated testing builds a very generalized understanding of a class of systems. We may still lack the ability to make the kind of situation-specific predictions enjoyed by engineers of less dynamic and open-ended systems ([Cabin 2011](#); [Meadows 2008](#))

While much work can be applied to increase the quantitative predictability of the ecosystem, in the meantime, many restoration decisions will be made based on a mixture of measurements, evidence, theories, intuitions, and visions—a combination of resources called best professional judgment. The human senses and brain have an enormous capacity to detect important patterns, integrate prior knowledge or concepts, and intuit evolution over time.

Aided by best professional judgement we can document observations using a range of simple technologies, from measuring tapes, to photographs, to systematic descriptions of pattern, color, and quantity. Over time, these informal observations can be used to develop postulates about how ecosystems function that can be the subject of future quantitative investigation. Where investigations are built on protracted and careful observation, we are more likely to make decisive and meaningful discoveries. Data collection, in the absence of protracted and careful observation, is unlikely to end in useful or robust analysis.

At risk of being patronizing, or obtuse, we suggest the following principles to support increased use and sharing of qualitative observation.

1. During development of designs, management strategies, and evaluation methods, identify specific locations and issues that could be subjected to careful observation.
2. Consider recording those observations as an important part of restoration practice.
3. Record observations using precise language and documentation that allows for a future third party to identify the location of the observation and compare current conditions to your observations.
4. Establish repeated observations of critical locations that allow for comparison among seasons or years. Review your past observations within a place before each subsequent visit to improve your ability to detect and understand change.
5. Make your observations available using [this wiki](#) so that others may learn from you and contribute their own observations.

Speculation can be discounted in professional practice, easily overwhelmed by decisive behavior and a piece of quantitative evidence held in the hand. It may take concerted effort to develop and engage our ability to cultivate clear and concise speculation, but I suspect it may actually be the most important missing ingredient to increasing learning in restoration practice.

Natural history records have their own rigor ([Herman 1993](#)) and have shaped the very bedrock of the natural sciences ([Darwin 1859](#)). The absence or presence of strong and well documented natural history observation in the practice of restoration may be decisive in our development.